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A Partially Translucent Mural Decoy

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Abstract

A novel improvement of two-dimensional decoys is presented, wherein light is diffusely scattered through translucent areas of the decoy when illuminated from behind, such that the effect of reflection from horizontal surfaces is simulated to an observer in front of the decoy. When illuminated in front, the same 2d decoy reflects light to the intended observer as would a completely opaque decoy. Thus, this flat representation of the 3d object has a dynamic component that changes with lighting conditions much as would the object being simulated, thereby enhancing the decoy's realism. The feasibility of this approach was demonstrated with a tank decoy. This invention is protected by US patent 5,599,023 (1997) [1].

1. Introduction: 3D vs. 2D Decoys

This new decoy concept builds upon experience Teledyne Brown Engineering gained in the 1980's from working on the Multi-spectral Close Combat Decoy (MCCD) for the US Army. That product was a two-dimensional mural which presented a visual and thermal IR image to the intended observer. (Although the present work builds solely on display of the visual image, future embodiments of the invention are envisioned which would extend its usefulness into NIR and thermal IR realms.)

An overriding assumption of the present work is that 2D decoys are useful to deception practitioners. Certainly three-dimensional decoys of military assets have superior fidelity under all view angles and lighting conditions, but tradeoffs in cost and logistics make two-dimensional decoys desirable in some situations, especially when given the improvements proposed in the present text.

In order for either an asset or decoy to be viewed in visible or NIR light it first has to be illuminated. Natural sources of illumination are, of course, direct sunlight or moonlight, sky radiance, and ground radiance. An accurate 3D replica of an asset automatically presents an good depiction of the asset with all the attendant shadows and variations of surface flux, as shown in the top portions of Figures 1.1 and 1.2. A typically opaque 2D decoy merely presents a flat image of the asset, but only when the front is illuminated (e.g., as in the bottom of Figure 1.1). Under conditions of strong direct illumination from behind, the illumination from sky and ground radiance may be inadequate to reveal a credible image and the decoy instead appears as a dark silhouette (bottom of Figure 1.2). Actual examples of a tank and a two-dimensional (opaque) decoy are depicted in Figures 1.3 and 1.4, respectively. The author believes Teledyne Brown has wasted energy in past efforts by striving to attain photographic realism of decoys only to have the image be practically invisible under certain lighting conditions. (e.g. Figure 1.4) The partially translucent decoy attempts to alleviate this problem by "borrowing" light from behind the image and diffusely scattering it forward where the intended observer may see it (Figure 1.5). By design, this brightening effect is created only in certain parts of the image that need it. In the present

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context these areas were the roof, upper hull, and upper parts of the fenders of a main battle tank. The rest of the image was opaque. This brightness enhancement adds a dynamic element to the decoy display, and creates the opportunity for further effects such as changing the lengths of depicted shadows (e.g. Figure 4.3). This technique of accepting light energy from the rear of a decoy to assist in illuminating its displayed image, plus the passive inclusion of dynamic lighting effects builds upon the work of the French artist Andre Roger Lannes DE Monteballo [2].

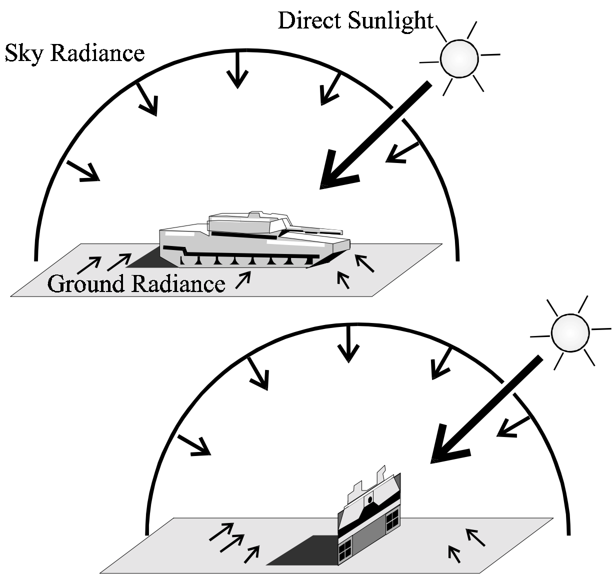


Figure 1.1 Front Illumination of an Asset or 3D decoy (top) and 2D Decoy (bottom)

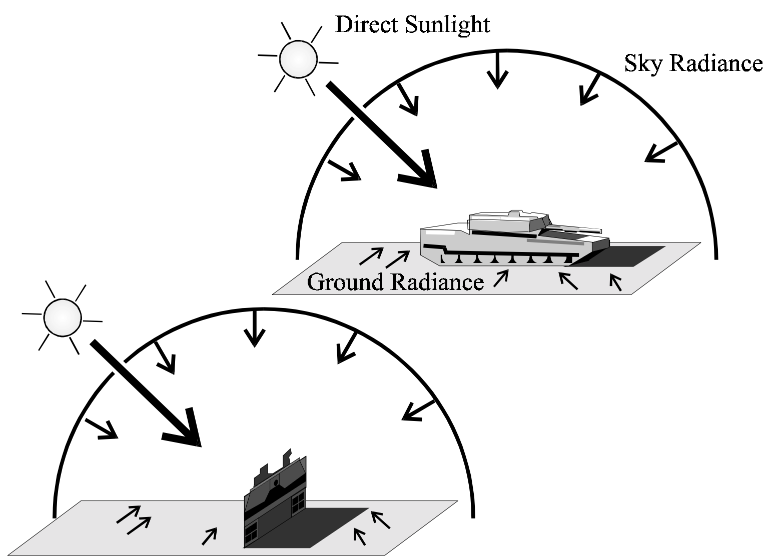


Figure 1.2 Back Illumination of an Asset or 3D decoy (top) and 2D Decoy (bottom)

Figure 1.3 A tank Under Strong Back Illumination.

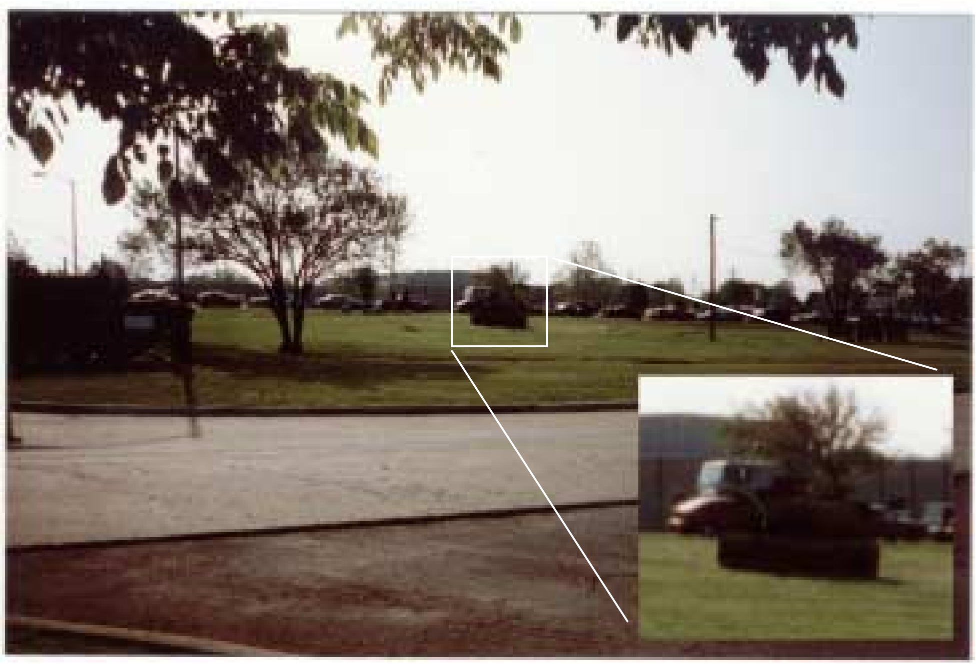


Figure 1.4 A Two-Dimensional Tank Decoy Under Back Illumination (MCCD).

Figure 1.5 A Partially Translucent Mural Decoy of a Tank. (Note silhouette of hand.)

2. Objectives for Constructing a Partially Translucent 2D Decoy

An exercise was conducted where a partially translucent decoy was designed, constructed, and field tested. This exercise had the following objectives:

Primary objectives

- Imitate a frontal M1 Abrams tank image leftover from our MCCD program.
- Incorporate translucency in roof, upper hull, and upper parts of the fenders of the tank image.
- Demonstrate the translucent technique with only visible light, and without requiring a practical design for field use.
- Add a main gun tube shadow for back lit conditions (a front lit case would have problems to overcome).
- Create the image using dyes on polyester fabric (no pigmented coatings) in order to minimize opacity changes in the fabric.
- Demonstrate the utility of translucency in a field test against a completely opaque decoy (MCCD).

Secondary objective

- Improve color and contrast over Teledyne Brown's past efforts in life-size tank graphics.

3. Construction

3.1. Support Structure

Since the decoy prototype was to concentrate on demonstrating the gains attained from translucency without concern for portability and storage, the test decoy used a plywood and

plexiglass back plane to which the cloth image was eventually glued (Figures 3.1 through 3.3). Some care was taken to taper the support structures immediately above the plexiglass pieces in order to minimize interference at high sun angles. The transparent plexiglass regions allowed light to pass through with little hindrance to illuminate the cloth image from behind, thus creating diffuse forward scatter through the cloth and thus the translucency effect. The plywood regions naturally provided opacity for the image regions that required it. Black cloth tape was used, where necessary, over translucent regions to precisely delineate opaque regions and add details. Here, the opportunity was used to create the impression of a turret shadow that lengthens under back lighting conditions. This effect was achieved by simply extending a region of opacity below the turret shadow as depicted within the image. When front lit, the original length shadow is seen. When back lit, the turret shadow appears to have crept outward along the hull (Figure 4.3). Also, an opaque region with a jagged outline simulated the shadows of equipment mounted on the turret roof under back illumination (Figure 4.4). Finally, a large cardboard tube of the approximate diameter of a main gun tube was attached behind the back plane so that a simulated gun shadow would fall across the "hull" region of the decoy image (Figures 3.2 and 4.1).

3.2. Image Design

The source image was a color proof leftover from Teledyne Brown's MCCD program. This particular image was of an M1 Abrams main battle tank, but missing more than a foot of height owing to missing ground clearance under the tank belly. This feature was maintained for the prototype decoy discussed here as it avoided the issue of having to simulate the open space beneath the tank and also made a more a direct comparison to the earlier decoy. (It is assumed that a knowledgeable deception practitioner would make a plausible display from such a decoy by making it appear to be in a shallow depression, behind brush or sandbags, or something of this ilk.) The image was scanned into a computer where it was manipulated with image software in order to help visualize the effect of adjusting some of the poorly saturated colors it contained. This scanned image was not used to directly create a color reproduction, as a modern print shop could do, because the cost of such an effort would have been prohibitive. However, the scanned image was made into two life-size paper paste-ups by way of laser printer output and xerographic enlargement. The first of these images was used for laying out the image onto cloth while the second was made into paper stencils for efficiently transferring detailed features of the roof, tracks, smoke grenade launchers, etc.

The actual tank depicted in the source image was covered with a typical green, brown, and black camouflage paint job. Actual color coordinates for these paint were acquired from a co-worker [3] and used in a laboratory color match after conversion to L*a*b* space (D65 illuminant) [4, 5]. Since the three-dimensional shape of the tank creates shadows, different surface irradiances, and specular effects, there are naturally differences in the perceived brightness of these areas. Since a flat decoy image typically has a constant level of illumination, the image itself must contain variations in reflectance in order to create the desired 3D effect. Thus, the color targets for the individual camouflage paints were split into two (for green and brown) or three (for black) new targets with different L* values but with fixed a* and b* values. The L* values were arbitrarily chosen to be around 36 to 40 (turret front), 60 (turret roof and top of hull), and 22 (deepest portion of turret shadow). Since intermixing of dyes, dilution of dyes with clear paste and water, and non-repeatability of hand brush application each conspired to create a range of L* values outside of the three stated, the new color targets only served as rough guides.

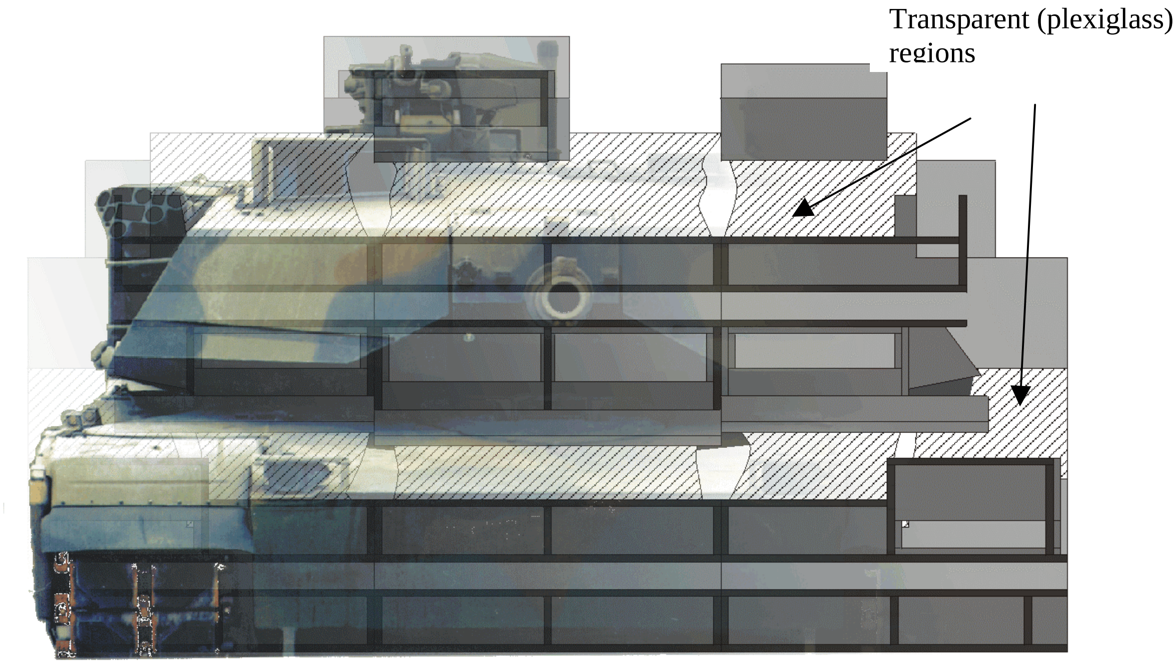


Figure 3.1 Composite View of Decoy Image and Underlying Support Showing Transparent Structural Members.

Figure 3.2 Rear View of Prototype Decoy During Field Test of 3/6/00.

Figure 3.3 Rear view of prototype decoy, showing tapered supports and a plexiglass stiffening member

Changes in color saturation (i.e., the distance of (a*, b*) coordinates from the L* axis) should be expected for near horizontal surfaces of the actual tank, and should thusly be expressed in the decoy image. Variations in saturation, however, were not formally attempted for the decoy image but probably arose as an inevitability of hand-painting the image.

Yellow, blue, rubine, and black disperse dyes, commonly used in textiles, were used to create the decoy image on polyester fabric. As an exercise, the color match was performed in iterative fashion without relying on any past experience with the particular dyestuffs, as the author demonstrated with pigmented coatings in [6]. Unfortunately, the match process was halted well before reasonable match errors (expressed as ΔE_{ab} of the order 1) were attained, owing to time constraints. These results are summarized in Table 3.1. (The difficulty of obtaining a good match here points to a possible inadequacy in characterizing the dyed polyester medium, which could force a refinement of the author's matching technique.) Surprisingly, the worst color match trials were those attempting to simulate black paint in the tank's camouflage pattern. This failure is due mostly to the automatic a*-b* mismatch of the black dye and the unwillingness of the author to remedy this mismatch by tinting the black dye with other colors. The characterization of laboratory color was performed with a Perkin/Elmer Lambda 3B spectrometer that was equipped with an integrating sphere.

Table 3.1 Summary of a Very Rough Laboratory Color Match.

Target	Target L*	Target a*	Target b*	Trial L*	Trial a*	Trial b*	Match error ΔE_{ab}
(Green 383)	**(32.5)**	**(-8.85)**	**(15.6)**	-	-	-	-
Med. Green.	40	-8.85	15.6	39.5	-5.55	15.2	3.4
Lt. Green	60	-8.85	15.6	59.7	-4.30	13.4	5.0
(Brown 383)	**(31.8)**	**(16.1)**	**(12.6)**	-	-	-	-
Med. Brown	36	16.1	12.6	33.8	16.1	10.95	2.7
Lt. Brown	60	16.1	12.6	60.0	15.8	10.8	1.8
(Black spec.)	**(21.9)**	**(4.90)**	**(-5.53)**	-	-	-	-
Dark black	21.9	4.90	-5.53	22.2	2.1	1.1	7.2
Med. black	~25	4.90	-5.53	31.6	1.9	1.5	10.1
Lt. Gray	~50	4.90	-5.53	59.9	0.16	-0.95	11.9

3.3. Dyeing the Image

The image was created on a white polyester, tablecloth-type fabric using brushed-on dye paste. In a production environment, these dye pastes could be used to screenprint the image. Unfortunately, the time and resources required for screenprinting a life-size tank image were prohibitive, so brushing the image on by hand was a necessary expedient. This particular fabric was chosen for its ability to diffusely scatter light in the forward direction, as judged from observations made of various cloth types encountered in a fabric store. (Subsequent work described in Section 5 supported this judgement.) Paints were not used to create the image because the additional scattering created by their pigments were seen as an unwanted variable. A dyed image, on the other hand, by relying on the cloth substrate for scattering power, should affect the amount of forward scattering less, so the amount of translucency would be closer to that seen when the undyed cloth was first evaluated. (Since the dyes present in the image will absorb some of the light scattered by the cloth, some increase in opacity regarding the diffusely transmitted light is unavoidable.)

The previously discussed dispersed dyes were made into a paste according to the formulations derived during the color match trial. The major part of the dye paste was made from a mixture of water and algin (a kelp-derived thickener), to which the dyestuffs were added in powder form. The dye pastes were brushed onto the cloth using a combination of freehand and paper stencil techniques. After drying the dyes were heat-set with an electric iron. Although the laboratory color matches made in support of this decoy were laundered in a washing machine (for the purpose of removing unbound dyestuff), the decoy image was left unwashed to save time. There were no color measurements made of the finished decoy image, although non-contact style measurements made on the intact decoy might be possible in the future.

4. Field Testing

A simple field test was conducted on the grounds of Teledyne Brown Engineering on March 6, 2000. This field test simply consisted of visually comparing the partially translucent 2D decoy next to an opaque decoy, the old MCCD. Both decoys faced west, and were photographed several times throughout the day (Figures 4.1 and 4.2). This field test was purely qualitative, but was felt by the author to adequately demonstrate the advantage derived by judicious use of translucency. This field trial was conducted on a clear day so strong direct illumination was

always present except at the time of the final photograph, taken at sunset (bottom frame of Figure 4.2).

Figure 4.1 Time Sequence from Decoy Field Test of 3/6/00. The partially translucent decoy is on the left side, the completely opaque decoy (MCCD) on the right. Times are (top to bottom): 07:25, 08:35, 10:15, 11:50, and 12:10.

Figure 4.2 Time Sequence from Decoy Field Test of 3/6/00. The partially translucent decoy is on the left side, the completely opaque decoy (MCCD) on the right. Times are (top to bottom): 13:40, 15:35, 17:05, 17:35.

The morning photos (upper portion of Figure 4.1) are characterized by bright areas of the hull and roof regions of the partially translucent decoy image (left of the figure) while the MCCD is all dark. This effect simulates the glare from the corresponding regions of the actual tank (Figure 1.3). There is also a simulated gun shadow projected onto the “hull” region of the partially translucent decoy during back illumination. This simulated gun tube shadow moves in response to sun position, much as would an actual gun tube shadow. Unfortunately, a similarly

robust gun shadow simulation is more difficult to create for front illumination, and so was not attempted.

The simulation of a changing turret shadow and of the appearance of roof accessory shadows was discussed in the context of the support structure, Section 3.1. Figures 4.3 and 4.4 contain composite images created from the field test photos in order to make these dynamic shadow effects more obvious. In these figures the simulated effects of a shifting turret shadow and of the disappearance of roof accessory shadows is quite apparent. Thus, the partially translucent 2D decoy simulates the dynamic lighting effects which would affect the actual tank, and in a completely passive manner.

Figure 4.3 Comparison of Back lit (left) and Front lit (right) Partially Translucent Decoy. Note the apparent shift of a turret shadow cast onto the hull. Times are 8:35 (left) and 15:35 (right) on 3/6/00.

Figure 4.4 Comparison of Back lit (top) and Front lit (bottom) Partially Translucent Decoy. Note the apparent shadows of roof accessories in the top image versus the bottom. Times are 8:35 (left) and 15:35 (right) on 3/6/00.

A secondary goal of the partially translucent decoy was to improve on the contrast evident in Teledyne Brown's past decoy work, which was achieved as shown in Figure 4.2 (particularly in the second frame from the bottom). Here, the darkest portion of the image was simply "anchored" to the lowest reflectance achievable with high loading of black dye on polyester, which was about 0.03. This is probably the lowest image reflectance that can be attained with the polyester substrate, since the refractive index mismatch of the fabric to the air will cause some reflectance at the fabric/air interface. Since the brightest regions of the partially translucent decoy are typically around 0.3 reflectance, the overall dynamic range of energy reflected from this decoy is around 10. Although this dynamic range is noticeably higher than that displayed by the MCCD, a human observer, having an instantaneous dynamic range of roughly 100, might perceive a contrast difference between this decoy and an actual tank under typical illumination.

5. Judging Translucency of Materials

In order to make of use of material translucency, some assessment had to be made of the diffuse scattering properties of potential materials. Although the final fabric choice for the decoy image was based on personal judgement, this choice was subsequently supported by laboratory tests. The criterion was simply that the material offer the most diffuse forward scattering in terms of both throughput and angular distribution. Diffuse transmittance measurements were later performed to quantify the amount of light "throughput". The reason for the criteria given above was for the translucent areas of the decoy to maximize their luminance upon back illumination with little sensitivity to observer position.

A simple apparatus was devised to qualitatively observe the amount of a material's diffuse transmittance relative to its reflectance. This device, which works well for diffusely scattering samples, is depicted schematically in Figure 5.1. Samples of the same material are mounted both perpendicular and flat to a baseboard. The baseboard is then positioned to allow direct sunlight to impinge at a 45° incidence to both samples, thus balancing the irradiance on each. The observer is positioned behind the perpendicular sample, such that he sees light diffusely transmitted by this sample while simultaneously observing light reflected by the flat-mounted sample. (The baseboard is painted a 3% flat black, making it a reasonably good backstop for this application.) In the figure the observer is depicted along the direction of specular reflectance of the flat-mounted sample, which was not a problem when dealing with the diffusely reflecting decoy fabric. (This observer direction, however, can be altered when dealing with materials possessing poorer diffusivity.) Figures 5.2 and 5.3 show the actual device in use. In the left side of Figure 5.3, both the (diffuse) forward and back scattering samples consisted of a single layer of the un-dyed decoy fabric. This photograph was taken from the observer position noted in Figure 5.1. Although it depicts a qualitative observation, this figure shows the material has the same rough magnitude of light power going through it as is bouncing off of it. The right side of Figure 5.3 depicts a similar situation, but for two layers of the same fabric in both sample positions, creating slightly more reflected and somewhat less transmitted light, although these differences are hardly apparent in the reproduction here.

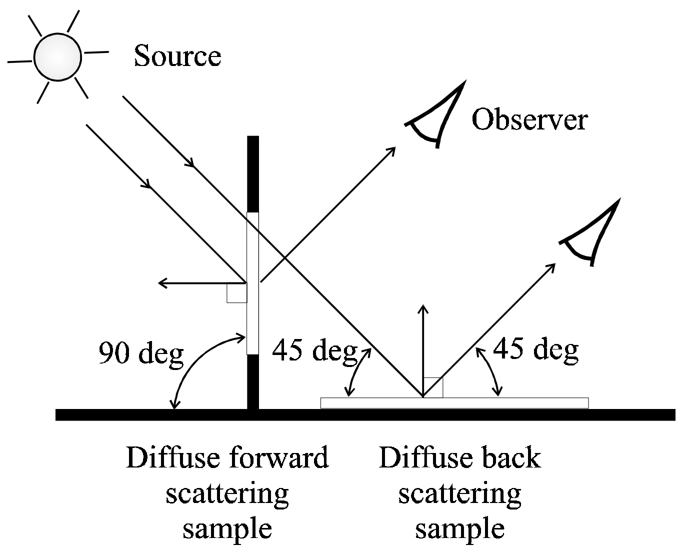


Figure 5.1 Schematic of a Low-Tech Apparatus for the Qualitative, Simultaneous Comparison of Light Scattered Diffusely in the Forward and Back Hemispheres.

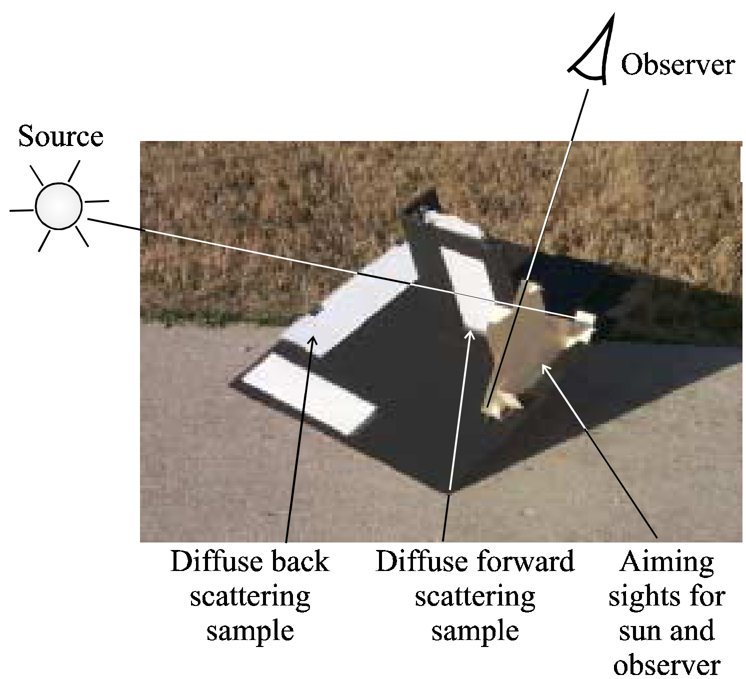


Figure 5.2 The Low-Tech Diffuse Scattering Apparatus With Two Samples of the Same Fabric.

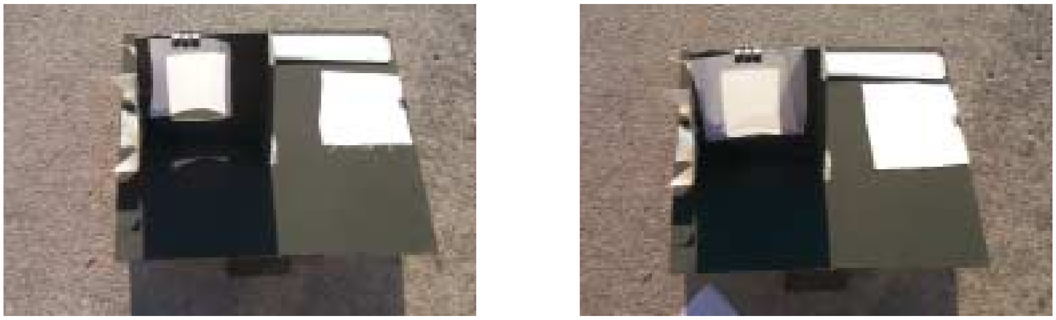
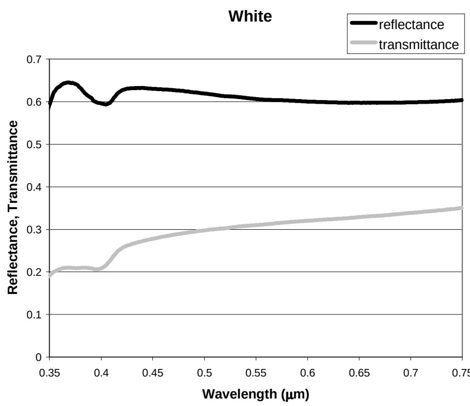
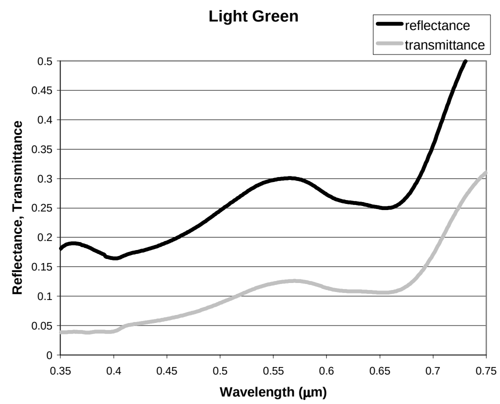


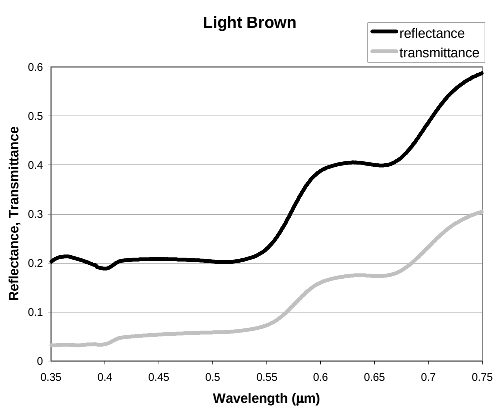
Figure 5.3 The Low-Tech Diffuse Scattering Apparatus as Seen From the Observer Position With Decoy Fabric Under Test. Left side: both samples are of a single fabric layer. Right side: both samples contain two layers of fabric.



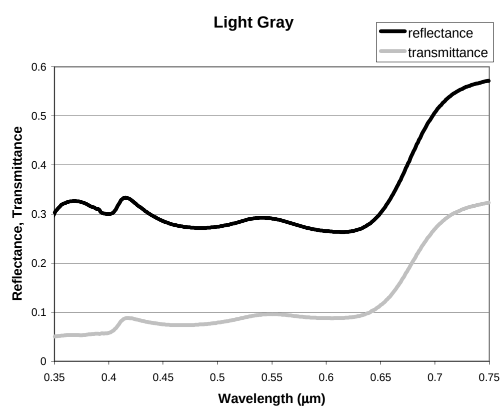
(a)



(b)



(c)



(d)

Figure 5.4 Comparison of the Diffuse Reflectance (black traces) and Diffuse Transmittance (gray traces) of Decoy Fabric: (a) Un-dyed; (b) Light Green; (c) Light Brown; and (d) Light Gray.

The claim was made above that the amount of light power for creating an image with the chosen fabric is the same rough magnitude for both reflected and transmitted light. This claim is substantiated somewhat by reflectance and transmittance measurements of the 0°/diffuse type. These measurements were done in the visible spectral band using the Perkin/Elmer instrument described in Section 3. The results are shown in Figure 5.4 for fabric which was un-dyed (case a), light green (case b), light brown (case c), and light gray (case d). The amount of light diffusely transmitted is typically 1/3 to 1/2 of the amount reflected. This rough parity of diffuse transmittance and reflectance was required in order for the decoy to have sufficient light power under back illumination to make a plausible image.

6. Conclusion and Discussion of Potential Improvements

The partially translucent two-dimensional decoy was shown to be a sound concept that promises to improve the realism of flat decoys while maintaining advantages of a 2D decoy, such as portability, easier storage, and lower cost. Improvements are possible in the areas of experimental measurement, decoy capabilities, and decoy producibility.

Potential Improvements in measurement and experimental design

- Make non-contact color measurements of the existing decoy.
- Conduct a field test with the decoy next to real tank and various lighting conditions.

Extensions to the capability of the partially translucent decoy:

- Add multi-spectral capability with NIR “color” matching, and possibly by including a heat source and creating a thermal image with emissivity variations.
- Use a collapsible support structure.
- Improve color rendering. Specifically, an image of a tank could be captured and calibrated according to the technique revealed in [7] and used as the source image of the decoy graphic. This calibrated image would be the ideal that the decoy would attempt to display, with the qualification that its contrast (or dynamic range of brightness) be reduced, if necessary, to accommodate that attainable with the decoy graphic (as discussed at the end of Section 4).
- Explore the simulation of polarization effects caused by the reflectance of light from real 3D assets.
- Explore using limited 3D-relief to create a gun tube shadow under front illumination (Figure 6.1).
- Explore using light collectors hidden behind the decoy to boost the brightness of the translucent areas during high sun angles (Figure 6.2).

Finally, improvements which will help the producibility of the decoy would be :

- Use screenprinting or other printing technique to mass produce the decoy images, possibly with a custom color separation.
- Print the opaque regions of the decoy as black areas either directly onto the back of the decoy image, or onto a separate, clear medium which is then sandwiched to the back of the decoy image.

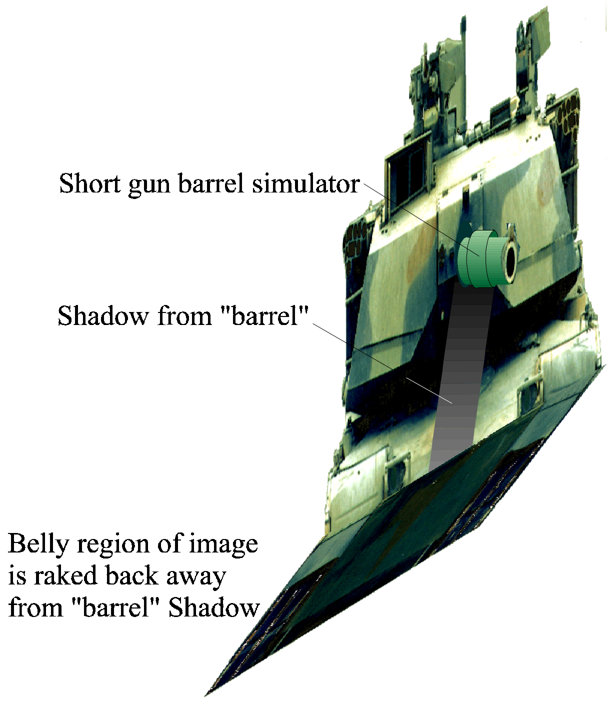


Figure 6.1 A Possible Mechanism for Creating a Dynamic Gun Tube Shadow Under Front Illumination.

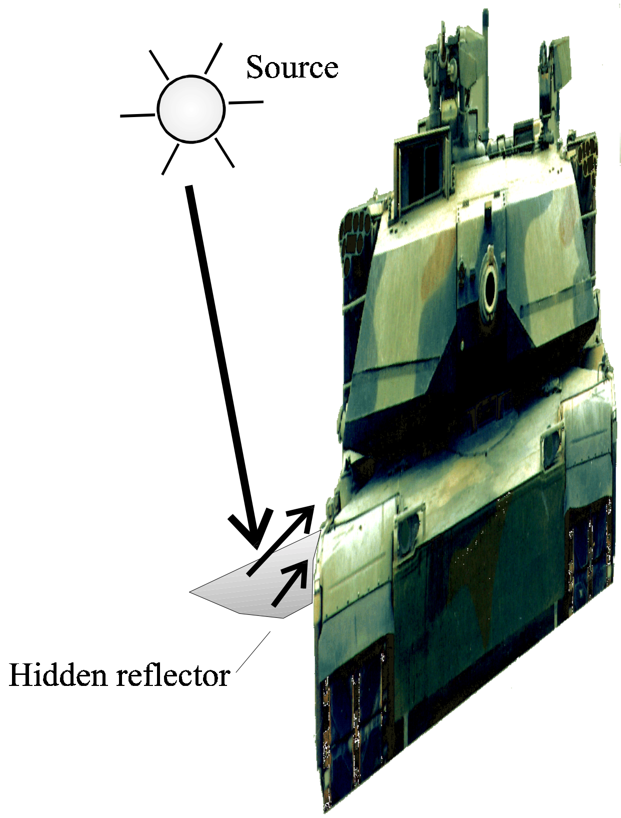


Figure 6.2 Boosting the Light Throughput of a Translucent Region with a Hidden Reflector.

Figure 6.3 The Author Relaxing After Decoy Construction.

1 Loyd, J., "Partially Translucent Mural Decoy" - US patent 5,599,023, 1997.

2 DE Monteballo, A. R. L., "Method and Apparatus for Providing from Plane Images the Appearance of a Solid Object", US Patent (2,647,336), 1953.

3 Watkins, L.J., Teledyne Brown Engineering, Private communication, January 2000.

4 Wyszecki, Gunter, and Stiles, W. S., *Color Science - Concepts and Methods, Quantitative Data and Formulae,* 2nd Ed., John Wiley and Sons, New York, NY, 1982.

5 Allen, Eugene, "Colorant Formulation and Shading", *Optical Radiation Measurements, Vol 2-Color Measurement,* ed. Franc Grum and C. James Bartleson, Academic Press, New York, NY, 1980.

6 Loyd, J., "Expedient Colorant Mixing Using Kubelka/Munk Single Constant Theory", Proceedings of the *1998 Meeting of the IRIS Specialty Group on Camouflage, Concealment, and Deception*, Vol. 1, ERIM International Inc., Ann Arbor, MI, 1999.

7 Reynolds, W., Houle, R., Hilgers, J., "Color Calibration of Digital Camera Imagery", Proceedings of the *1998 Meeting of the IRIS Specialty Group on Camouflage, Concealment, and Deception*, Vol. 1, ERIM International Inc., Ann Arbor, MI, 1999.